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THE SECULAR VARIATION OF CLIMATE

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The influence of variations of the sun's radiation on terrestrial climate has been the subject of many mathematical investigations. In former years these have dealt almost exclusively with the "sun-spot period" of approximately eleven years; more recently variations of shorter period, from a few days up to five years, have come into favor. But with all these periods the problem is complicated by the fact that the variations of terrestrial climate directly dependent upon variations in the supply of solar heat, themselves cause further terrestrial changes, and so on in an endless chain. Even the eleven-year "sun-spot period" is apparently not long enough for these repercussions to die down sufficiently to allow us a clear vision of the relation between the solar cause and the terrestrial effect. The shortest oscillations of a few days period have the advantage of instant and obvious action on temperature, but they have little effect on other elements and apply only in certain favored regions.

Table I—Sun-Spot Numbers, 1749–1918

Year	0	1	2	3	4	5	6	7	8	9
1740	..	..	..	..	..	..	..	..	..	81
1750	83	48	48	31	12	10	10	32	48	54
1760	63	86	61	45	36	21	11	38	70	106
1770	101	82	66	35	31	7	20	92	154	126
1780	85	68	38	23	10	24	83	132	131	118
1790	90	67	60	47	41	21	16	6	4	7
1800	14	34	45	43	48	42	28	10	8	2
1810	0	1	5	12	14	35	46	41	30	24
1820	16	7	4	2	8	17	39	50	62	67
1830	71	48	28	8	13	57	122	138	103	86
1840	63	37	24	11	15	40	62	98	124	96
1850	66	65	54	39	21	7	4	23	55	94
1860	96	77	59	44	47	30	16	7	37	74
1870	139	111	102	66	45	17	11	12	3	6
1880	32	54	60	64	64	52	25	13	7	6
1890	7	36	73	85	78	64	42	26	27	12
1900	10	3	5	24	42	64	54	62	49	44
1910	19	6	4	1	10	46	55	99	78	..

In these circumstances it seemed desirable to go to the other extreme and study the connected variations in what may be called their "secular" trend. Table I shows Wolfer's sun-spot "relative numbers" from 1750 to date, and Figure 1 shows the same numbers graphically, smoothed over an eleven-year period, each eleven-year mean being entered to the middle year. This brings out a longer variation of no particular period. The last chief maximum occurred about 1835; but the curve rose to almost the same point in 1870, and the subsequent decline is still in progress.

It is on this last phase that attention is concentrated in this study. By 1870, or shortly after, a large number of meteorological stations had been established in all parts of the world, and many long series of homogeneous observations are now available for study. Most of those employed here were collected by G. T. Walker of the Indian Meteorological Office for an investigation of the relations of climate and sun spots and were generously made available for other investigators;[1] a few other figures have been collected for unrepresented or specially interesting areas. These figures have been analyzed for secular variation by the method of correlating with time.

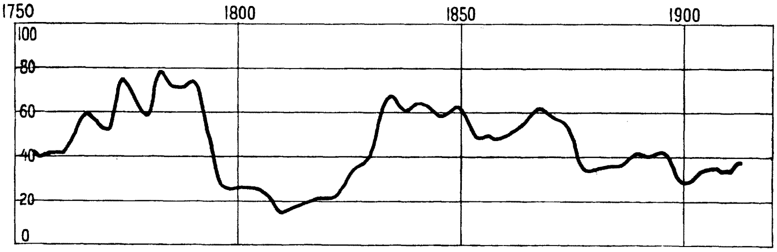

FIG. 1—Sun-spot numbers (eleven-year means).

The process is as follows: The series of, say, mean annual pressures are represented by deviations, $p1$, $p2$, $p3$, . . . pn, from their common average and arranged in a column with their earliest year at the top. Against the middle year of the series is written 0, and from this line the figures $-1, -2, \ldots -n/2$ are written upwards and the figures $1, 2, \ldots n/2$ downwards so that the earliest year has the value $-n/2$ and the latest year $n/2$. The following sums are then calculated:

the squares of $p1, p2, \ldots pn = \Sigma p^2$
the squares of $-n/2, -n/2+1, \ldots +n/2 = \Sigma y^2 = n(n+1)(2n+1)/3$
the products $p1(-n/2), p2(-n/2+1), \ldots pn(n/2) = \Sigma p.y$

The correlation coefficient r is given by the formula:

$$r = \frac{\Sigma p.y}{\sqrt{\Sigma p^2 \Sigma y^2}}$$

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[1] G. T. Walker: Correlation in Seasonal Variations of Weather, *Memoirs Indian Meteorol. Dept.*, Vol. 21, Parts IX–XII, (= pp. 12–118), Simla, 1914, 1915.

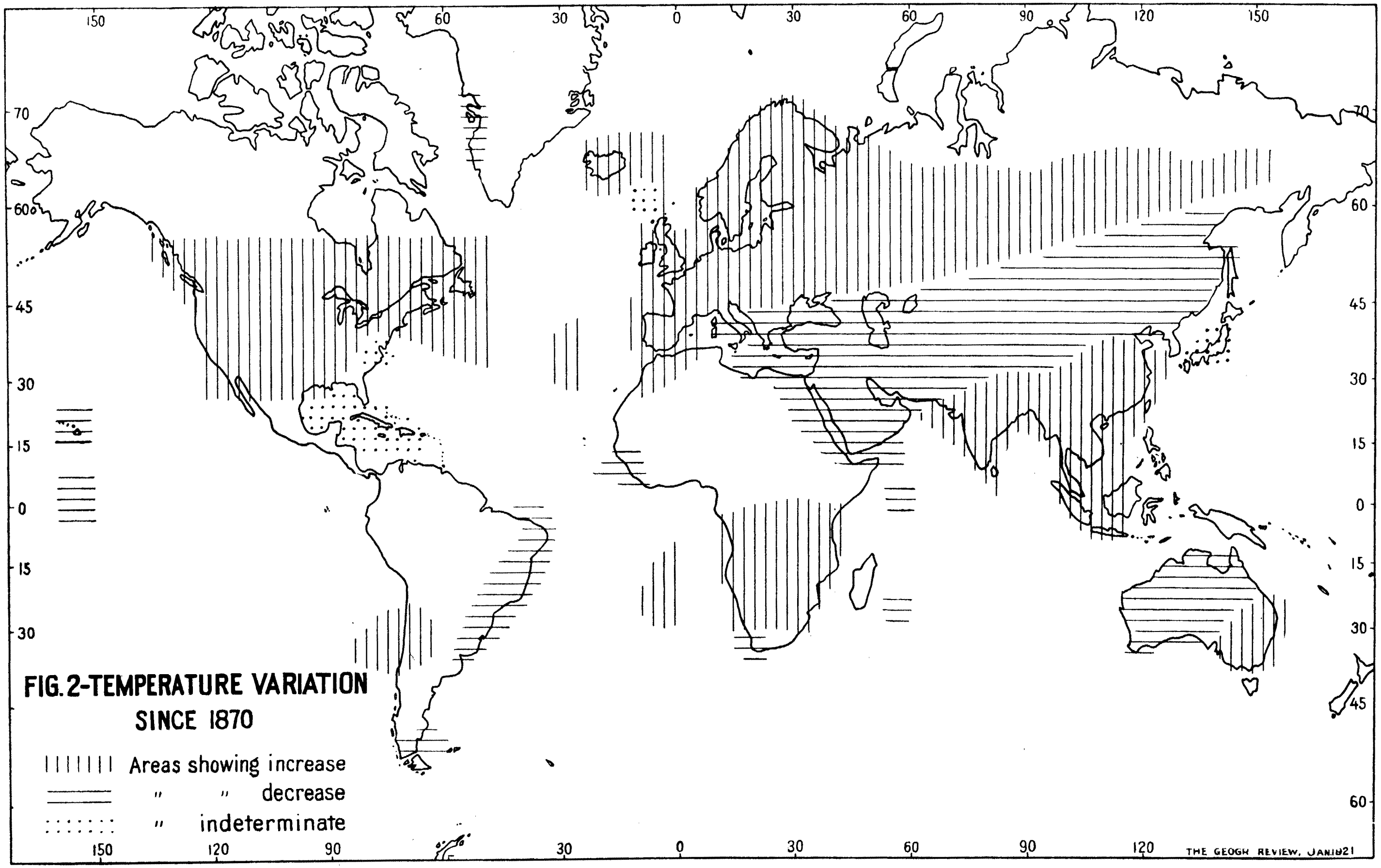

FIG. 2-TEMPERATURE VARIATION SINCE 1870

This gives the closeness of the connection between the variations of pressure at the station in question and the advance of time. A perfectly regular increase of pressure gives a correlation coefficient of $+1$, complete independence gives 0, and a perfectly regular decrease gives -1.

A figure of greater practical value is represented by b, which is the coefficient of the regression equation:

$$p = b.y$$

b thus gives the average amount by which pressure increases or decreases each year. Finally e is the probable error of the correlation coefficient, which means that the chances are even whether the real value of r, as distinct from the calculated value, lies between or outside the limits $r + e$ and $r - e$. For a value of r to have an undoubted significance it should be at least three times the value of e, unless other considerations come in.

Since the figure which is being employed ultimately—the average change per year—could have been calculated much more rapidly by a simple application of the method of least squares,[2] it may be asked why go to the labor of computing correlation coefficients? The answer is that the latter show how much of the observed standard deviation can be attributed to the secular variation and how much is due to other causes. The results of this part of the investigation will be referred to later, in connection with Table II, which gives the values of r, b, and e for a large number of stations, classified geographically, for pressure and temperature. Similar values for rainfall were communicated to the Royal Meteorological Society recently in a paper entitled "The secular variation of rainfall."[3]

Distribution of Climatic Changes

So much for the mathematical part of the investigation. In Figures 2, 3, and 4 are shown the results of plotting the values of b. Areas where the element in question has been increasing since 1870 are shown by vertical shading, areas of decrease by horizontal shading; indeterminate areas are stippled, and unrepresented regions are left blank. The results are sufficiently striking. Considering first temperature (Fig. 2), we have the following definite areas of increase:

1. Temperate North America, most of Europe, and northern Siberia.
2. Southeastern Asia.
3. Northern Chile, South Africa except the tip, and southeastern Australia.

Areas of decrease are:

4. Western Greenland.
5. A belt including eastern South America, most of northern Africa, Arabia, and Central Asia to Saghalien.
6. Most of Australia and the tropical Pacific.

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[2] E.g. by the formula: $b = \frac{3\Sigma\, p.y}{n\,(n + 1)\,(2n + 1)}$

p being deviation from normal and y difference of date from middle year.

[3] *Quart. Journ. Royal Meteorol. Soc.*, No. 191, Vol. 45, 1919, pp. 233–248.

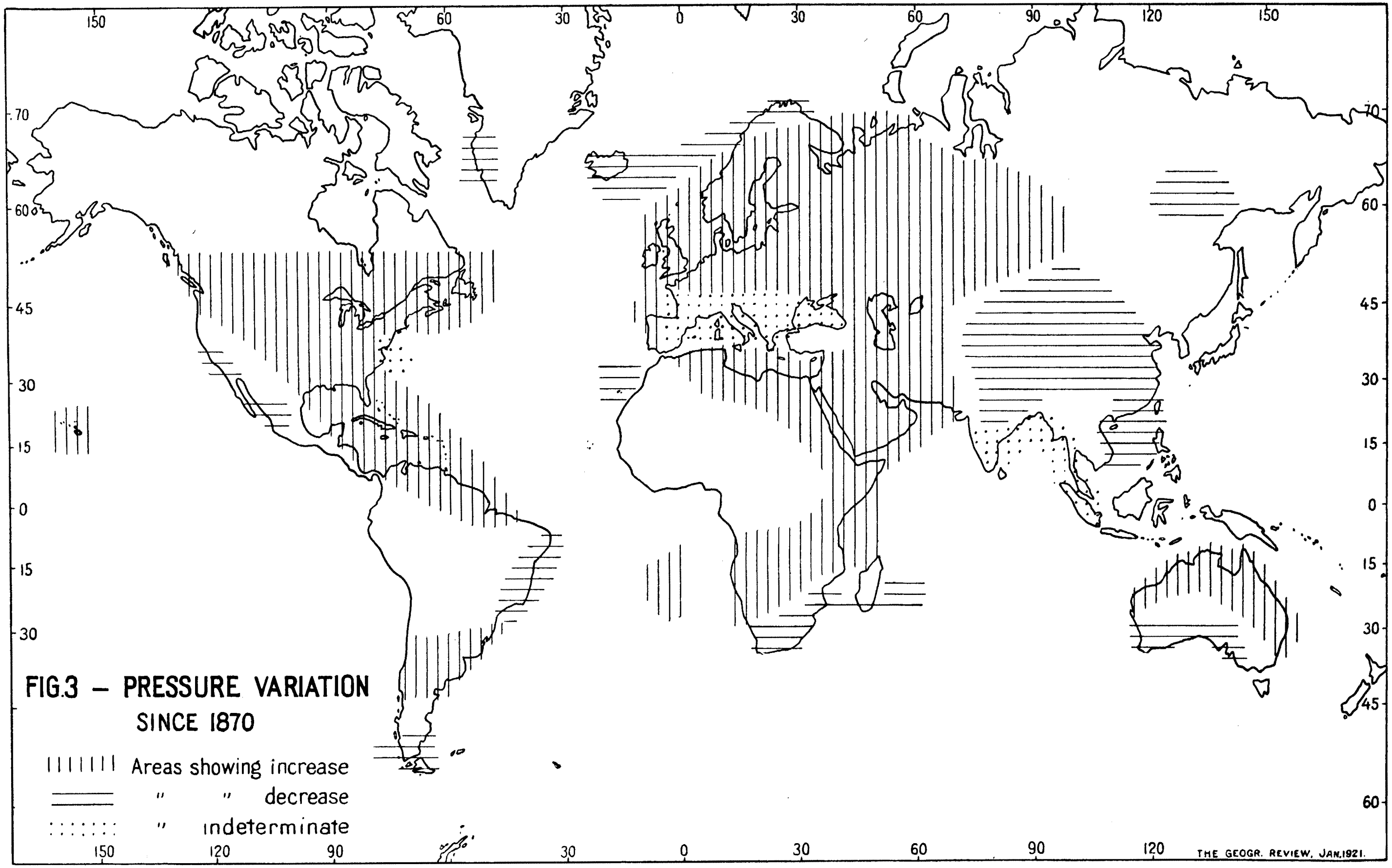

FIG. 3 – PRESSURE VARIATION SINCE 1870

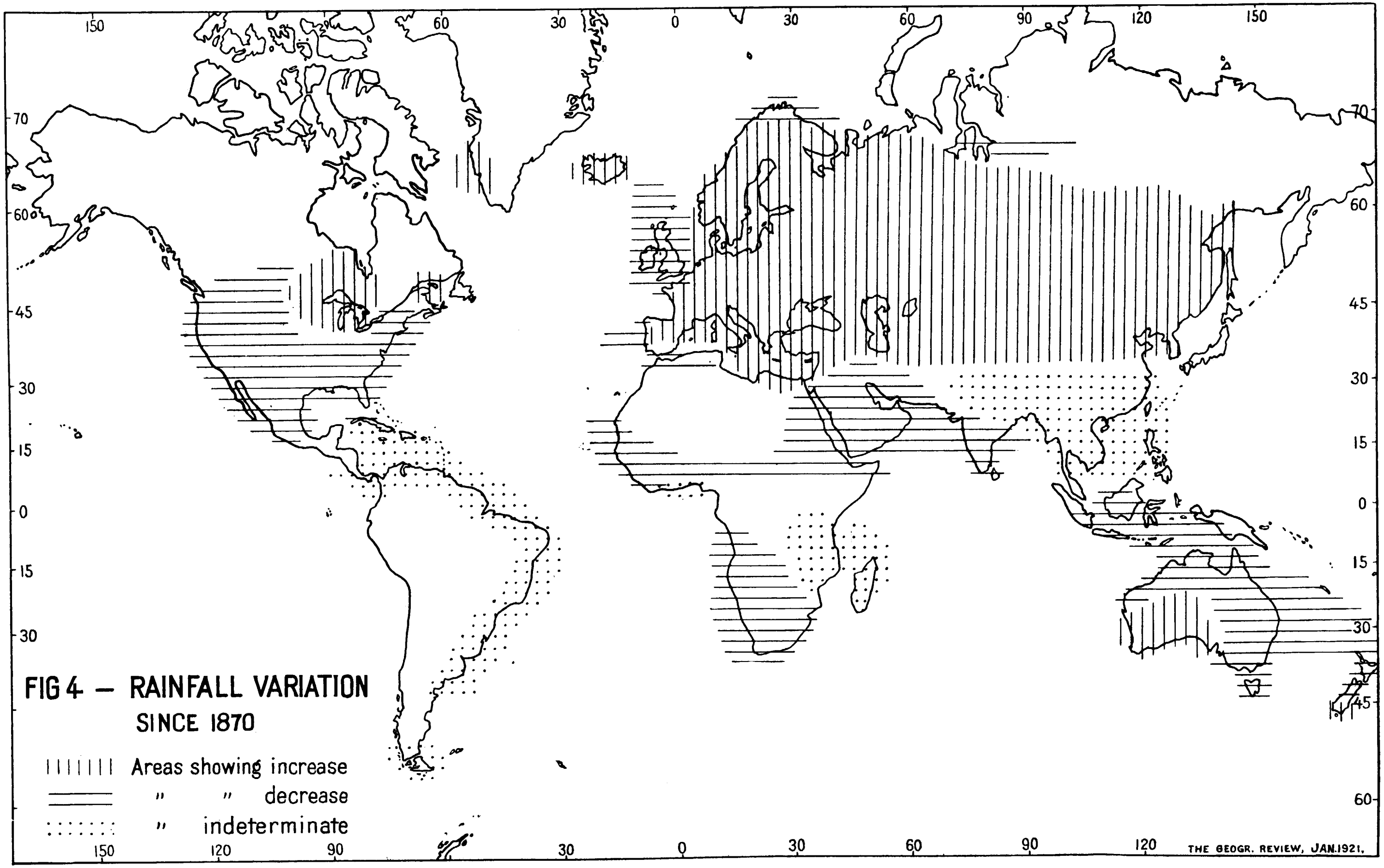

FIG 4 — RAINFALL VARIATION
SINCE 1870

THE GEOGR. REVIEW, JAN. 1921.

Similar areas can be determined in the maps of pressure (Fig. 3) and rainfall (Fig. 4).

Now we have to bear in mind two important points:

1. A decrease in sun-spot numbers is closely associated with a decrease in the total amount of radiation emitted by the sun. Consequently since 1870 the solar radiation reaching the upper limit of the earth's atmosphere has been decreasing.
2. The world may be classified into two types of climatic areas:
   - A. Dependent directly on the heat received from the sun—most of the tropics; Central Asia.
   - B. Dependent more closely on variations in the atmospheric circulation —the temperate storm belts and the permanent subtropical anticyclonic regions.

Changes in Tropical Regions

Returning to Figure 2, we find a tendency for the equatorial regions to show a fall of temperature since 1870. This is of great interest, as it is conformable with the decrease of heat received at the limit of the earth's atmosphere, instead of being opposed to it as in the case of the eleven-year period. The theory of the latter is that owing to the peculiar properties and action of the earth's atmosphere, a small increase in the total heat received results in an actual decrease of temperature at the earth's surface. But obviously this process has limits, and even in the sun-spot period the minimum temperature occurs about two years before spot maximum. It seems that the much greater range of solar heat in the last forty or more years has sufficed to overpower this secondary effect and give the temperature variation in the tropics a course roughly parallel to that of the solar heat. But it will be seen later that where the sun-spot secular variation curve flattens out there is a tendency for the temperature to rise again in spite of the fall during the earlier period.

The chief exception to the progressive fall in the tropics is the monsoonal region of southeastern Asia. In the interior of Asia the decrease of temperature has been very marked. Figure 3 shows that the decrease of temperature in the equatorial regions has been accompanied very closely by a rise of pressure, and Figure 4 shows a corresponding decrease of rainfall. In both cases the relationship is obvious: the air has become colder; hence it has also become heavier, while evaporation and therefore rainfall have diminished.

Changes in Extratropical Regions

In the regions dependent chiefly on the variations of the atmospheric circulation the case is more complicated. The strength of the circulation in extratropical regions depends chiefly upon the relative intensity of the low-pressure centers in the cold temperate zone, compared with the subtropical anticyclonic belts. The latter have shared in the equatorial rise of pressure, and, since the average pressure over the globe must remain approximately the same from year to year, this rise implies a corresponding decrease in higher latitudes. Consequently there should have been an increase in the poleward pressure gradient giving increased strength to the prevailing westerly winds of temperate latitudes. The map (Fig. 3) shows increases of pressure at Honolulu, over the West Indies anticyclonic region, and over northern Africa in the northern hemisphere; also over the subtropical high pressure belt in South America, South Africa, and northern Australia in the southern hemisphere. California seems to be an exception. On the other hand, there has been a fall of pressure in the Iceland-Greenland minimum and over the storm centers of Tierra del Fuego, Cape Colony, and the southern coast of Australia. So far so good.

NORTHWESTERN EUROPE

The relations of pressure variations to temperature and rainfall are shown best in the storm area of northwestern Europe. The marked decrease in the pressure at Iceland (60 units) and Greenland (71 units), combined with the increase over Europe, must have increased the strength of the southwesterly winds very considerably. The normal pressure difference between Iceland and southeastern England is about 12 millibars. During the last forty years this has increased at the average rate of about 0.1 mb. a year, a difference of 4 mb. between the first and last years of the series, which means that the resultant southwesterly current must have increased by almost 50 per cent during that period, a very important change. Hence a steady increase in the temperature of western Europe. The pressure decrease apparently extended into the Arctic Ocean (Vardo 9 units) and northern Siberia (Irkutsk 19, Yakutsk 20 units), and under its influence the belt of rising temperature passed right across the Siberian plain almost to the Pacific, its southern limit gradually shifting polewards on the way. There has been at the same time an increase of precipitation (except over the British Isles, which lose rainfall when depressions are able to pass rapidly northeastwards instead of hanging round the Atlantic coast). On the western side of the Iceland-Greenland minimum there must have been an increase of northerly winds, and a fall of temperature is shown. The increase of rainfall probably indicates an increased westerly or on-shore component in the wind.

STORM BELT OF THE SOUTHERN HEMISPHERE

In the storm belt of the southern hemisphere conditions are different in that there is no equatorial component in the wind, which is almost due west at Cape Horn and rather southwest at Cape Town and Perth, Western Australia. Consequently increasing the pressure gradient increases the cloudiness without bringing in warmer air, and a fall is shown in the temperature. Eastern Australia is an exception; here the wind normally comes from lower latitudes, and there has been an increased northwesterly gradient; hence more warm air has come in and temperature has risen; but, as the air is from the dry interior, rainfall has decreased.

TEMPERATE NORTH AMERICA

Temperate North America shows rather curious conditions. There has been a definite rise of pressure, except for a slight fall in the coastal regions of California. This is part of the general rise over the continents. It is unfortunate that there is no long uniform series from Alaska. The normal pressure gradient favors northwesterly winds over North America, and the general trend of pressure changes since 1870 has been to weaken this gradient; hence higher temperatures. At the same time the more anticyclonic conditions caused a decrease of the rainfall, except in eastern Canada, which has come under the influence of easterly oceanic winds from the Atlantic, caused by the relative increase of pressure over the St. Lawrence estuary and bringing increased rainfall.

MONSOON AREA OF SOUTHEASTERN ASIA

A remarkable exception to the general trend of variation in the tropics is shown by the monsoon area of southeastern Asia. Instead of falling temperature, rising pressure, and decreasing rainfall, this unit shows rising temperature over approximately its whole area and, except in southern India, falling pressure and indeterminate rainfall. Southern India has apparently been unable entirely to throw off its tropical characteristics and shows indefinite pressure variations and decreasing rainfall. The cause of these exceptional variations is obscure but can reasonably be connected with the variations farther north. The general changes of pressure over Siberia indicate an increase of the westerly component of the wind and a decrease of the northerly component. This means that the cold air of northern Siberia is carried off eastward and that less of it penetrates to southern Asia as the northeasterly monsoon. This monsoon is the principal agent in lowering the temperature there. There results an increased average temperature in the regions subject to the northerly winds in winter, which in turn lowers the pressure. The gradient for the southerly monsoon becomes stronger, and this further raises the temperature and contends, though with only partial success, against the normal tendency of equatorial regions towards an increasing drought.

PRACTICAL VALUE OF THIS STUDY

Having discussed briefly the extremely interesting principles of the mechanism of climatic changes raised by this study, a word may be said as to its practical value. It often happens in climatological work that a series of figures of, say, rainfall is not strictly homogeneous. There may have been a change of station from one part of the town to another. By means of an overlapping period factors may be obtained for reducing the earlier series to the same conditions as the later. The reduction may appear to be sound, and yet some doubt may attach to the result. A single example will suffice. In the course of preparing normals for use in the *Reseau Mondial*, a rainfall series at Villa Colon (1883–1905) was combined with a later one at the Central Observatory (1901–1918) to obtain a long-period normal of rainfall at Montevideo. The overlapping period of five years should have sufficed, considering the near neighborhood of the two stations, but on completing the work the earlier series was found to show a considerably smaller rainfall than the later series. The figures actually were: 1883–1900, 32.0 inches a year; 1901–1918, 39.0 inches a year.

This indicates a value of b equal to + 0.4 inches, i.e. the rainfall has been increasing at the average rate of 0.4 inches a year. This is considerable and would have thrown suspicion on the accuracy of the reduction; but reference to the rainfall paper already cited showed for Buenos Aires a value of + 0.75 inches for b during the period 1861–1907. This sufficiently confirms the increase at Montevideo, and the long period normal was accepted. A similar method has been applied to many doubtful series, with great success in separating the sound from the unsound.

The values of the correlation coefficients given in Table II are not in general large. This was to be expected and merely shows that the amount of the average year to year change throughout the whole period is not sufficient to dominate the irregular fluctuations and variations of the short period. Considering the multiplicity of agents which affect climate, it would indeed have been surprising if any other result had been found. Even so, some very remarkable results may be noted. In the West Indies we have two concordant high values of pressure: + .75 at San Juan, Porto Rico, and + .78 at Havana, continued in a northwesterly direction by + .36 at Key West, + .33 at Galveston, and + .46 at Denver, Colo., and in a southeasterly direction by + .20 at Para and + .61 at Blumenau—the six stations having a mean value of + .56. In southeastern Asia we have − .60 at Manila, − .33 at Hongkong, and − .39 at Zikawei. An area of high positive coefficients is found in eastern and northern Australia. These are all tropical or subtropical regions where the irregular fluctuations reach a minimum; in higher latitudes the reverse is the case, but even here we have to notice − .48 at Jacobshavn and − .39 at Stykkisholm.

In the case of temperature the values are as a whole smaller, indicating greater irregularity in this element. The thirteen stations in northern Europe, which are all positive, have a mean value of only − .23. The highest numerical value is − .76 at Mauritius; but western and northern Australia have also some high negative values: − .70 at Carnarvon, − .31 at Alice Springs and Port Darwin, and − .59 at Perth—mean − .48. For rainfall I may quote a high positive area in central Siberia (mean of five stations + .54) and a highly negative area between Sierra Leone and the Azores (mean of four stations − .47).

TABLE II—RESULTS OF CORRELATION OF MEAN ANNUAL PRESSURE AND TEMPERATURES WITH TIME

STATION	LAT.	LONG.	PRESSURE					TEMPERATURE				
	Deg. Min.	Deg. Min.	No. Yrs.	σ	r	e	b	No. Yrs.	σ	r	e	b
NORTH AMERICA	N	W		$\frac{\text{mb}}{100}$			$\frac{\text{mb}}{1000}$		°C			$\frac{°\text{C}}{1000}$
Albany, N. Y.	42 39	73 45	39	74	+.11	.10	+2	36	0.84	+.18	.11	+13
Denver, Colo.	39 45	105 0	40	47	+.46	.08	+19	40	0.64	.00	.11	0
Galveston, Tex.	29 18	94 50	40	71	+.33	.09	+20	40	0.47	+.06	.10	+2
Helena, Mont.	46 34	112 4	31	54	+.22	.12	+13	33	0.75	+.08	.11	+7
Key West, Fla.	24 34	81 49	40	54	+.36	.09	+18	40	0.49	−.55	.07	−23
St. Louis, Mo.	38 38	90 12	..	....	....	..	....	40	0.72	+.17	.10	+11
San Diego, Cal.	32 43	117 10	40	57	−.07	.10	−3	40	0.52	−.07	.11	−4
Sydney, N. S.	46 10	60 10	36	90	+.43	.09	+36	36	0.74	+.14	.11	+10
Toronto	43 29	79 23	41	63	+.05	.10	+3	36	0.88	+.37	.09	+32
Victoria, B. C.	48 24	123 19	21	74	+.26	.14	+31	22	0.73	+.57	.10	+66
Washington, D. C.	38 54	77 3	40	69	−.20	.10	−12	40	0.57	−.19	.10	−9
Winnipeg, Man.	49 51	97 7	20	78	+.18	.14	+21	20	1.07	+.61	.10	+100
ICELAND, GREENLAND, AND FAROES												
Jacobshavn	69 13	51 2	42	180	−.48	.08	−71	38	1.41	−.05	.11	−6
Stykkisholm	65 5	22 46	42	185	−.39	.09	−60	42	0.78	+.27	.09	+17
Thorshavn	62 22	6 44	42	143	−.06	.10	−7	39	0.44	−.03	.11	−1
NORTHERN EUROPE												
Archangel	64 33	40 32 E	34	166	+.32	.10	+55	26	1.10	+.27	.12	+27
Basel	47 33	7 35 E	41	96	−.03	.10	−2	38	0.58	+.01	.11	+5
Christiansund	63 7	7 45 E	45	144	+.11	.10	+12	37	0.65	+.34	.10	+19
Greenwich	51 29	0 0	41	142	+.30	.09	+36	41	0.58	+.22	.10	+11
Hamburg	53 33	9 59 E	36	107	+.06	.11	+5	36	0.64	+.62	.07	+38
Kieff	50 26	30 31 E	..	....	....	..	....	38	0.81	+.19	.10	+14
Lugansk	48 35	39 20 E	..	....	....	..	....	35	0.86	+.33	.10	+28
Moscow	55 46	37 40 E	..	....	....	..	....	38	0.95	+.13	.11	+11
Petrograd	59 56	30 16 E	38	140	+.02	.11	+3	38	1.01	+.21	.10	+19
Valencia	51 56	10 15W	43	179	+.04	.10	+6	27	0.36	+.09	.13	+4
Vardo	70 22	31 8 E	42	155	−.07	.10	−9	39	0.78	+.13	.10	+9
Vienna	48 15	16 21 E	40	89	+.10	.10	+7	41	0.60	+.12	.10	+6
Warsaw	52 14	21 2 E	38	81	+.39	.09	+29	38	0.79	+.28	.10	+20
NORTHERN ASIA	N	E										
Astrachan	46 15	48 4	30	73	+.27	.11	+20	24	0.68	−.09	.13	−6
Barnaul	53 20	83 47	38	101	+.17	.10	+15	38	0.85	+.38	.09	+29
Ekaterinburg	56 50	60 38	..	....	....	..	....	38	0.77	+.18	.10	+13
Yeniseisk	58 27	92 6	34	148	+.02	.11	+3	34	1.09	+.40	.10	+40
Irgiz	49 30	60 18	..	....	....	..	....	27	0.90	+.17	.12	+20
Irkutsk	52 16	104 19	35	136	−.15	.11	−19	35	0.43	−.50	.08	−21
Yakutsk	62 1	129 43	19	101	−.12	.15	−20	19	0.81	+.03	.15	+4
Nikolaevsk	53 8	140 45	..	....	....	..	....	31	0.70	−.07	.12	−5
Obdorsk	66 31	66 35	..	....	....	..	....	25	1.40	+.41	.11	+77
Tashkent	41 20	69 18	30	108	−.11	.12	−11	30	0.73	−.28	.11	−19
Turukhansk	65 55	87 38	..	....	....	..	....	22	1.06	+.25	.13	+35
CENTRAL AMERICA AND WEST INDIES	N	W										
Barbados	13 8	59 40	29	51	+.13	.12	+7	..	...	....	..	....
Bermuda	32 18	64 47	29	88	−.33	.11	−32	..	...	....	..	....
Grenada	12 5	61 40	..	....	....	..	....	25	0.23	+.45	.11	+15
Havana	23 0	82 15	40	72	+.78	.04	+53	..	...	....	..	....
Mexico City	19 26	99 8	34	57	−.07	.11	−4	34	0.36	−.01	.11	−1
San Juan, Porto Rico	18 25	66 7	40	75	+.75	.05	+52	..	..	....	..	....
MEDITERRANEAN REGION AND ARABIA												
Aden	12 45	45 3 E	32	40	+.33	.11	+14	30	0.28	−.10	.12	−3
Lisbon	38 43	9 9W	40	81	+.51	.08	+55	28	0.58	+.49	.10	+35
Malta	35 54	14 31 E	..	....	....	..	....	30	0.51	−.03	.12	−1
Palermo	38 7	13 22 E	28	69	.00	.13	0	..	...	....	..	....
Ponta Delgada	37 45	25 41W	..	....	....	..	....	25	0.43	+.19	.13	+9
Rome	41 54	12 27 E	..	....	....	..	....	40	0.37	−.10	.10	−3
Skutari	41 0	29 3 E	33	69	−.28	.11	−10	33	0.56	−.03	.12	−2
Tiflis	41 43	44 48 E	38	55	+.35	.09	+18	38	0.62	−.51	.08	−29

TABLE II—(*Continued*)

Station	Lat.	Long.	Pressure					Temperature				
	Deg. Min.	Deg. Min.	No. Yrs.	σ	r	e	b	No. Yrs.	σ	r	e	b
				mb/100			mb/1000		°C			°C/1000
INDIA AND PERSIA	N	E										
Agra	27 10	78 5	39	49	−.25	.10	−11	39	0.49	+.09	.11	+4
Bagdad	33 21	44 28	17	41	+.04	.16	+3	21	0.72	+.21	.14	+23
Bombay	18 54	72 49	43	41	+.01	.10	0	36	0.34	+.46	.09	+15
Bushire	28 59	50 49	34	41	+.03	.11	+1	34	0.48	−.29	.10	−13
Calcutta	22 32	88 20	43	39	+.03	.10	+1	36	0.36	+.41	.09	+14
Colombo	6 56	79 32	44	41	+.11	.10	+4	39	0.31	+.24	.10	+7
Leh	34 10	77 42	34	83	+.50	.09	+41	36	0.77	−.52	.08	−37
Madras	13 4	80 14	43	44	−.14	.10	−5	36	0.30	+.45	.09	−13
Rangoon	16 46	96 13	38	43	+.20	.10	+8	38	0.36	+.09	.11	+3
SOUTHEASTERN ASIA												
Batavia	6 11 S	106 50	40	48	+.01	.10	0	40	0.49	+.38	.0	+16
Hongkong	22 18 N	114 11	28	47	−.33	.11	−19	28	0.35	+.50	.09	+21
Manila	14 35 N	120 58	34	59	−.60	.07	−35	34	0.45	−.54	.08	−25
Nagasaki	32 48 N	129 57	26	56	+.17	.13	+12	33	0.54	−.17	.11	−9
Peking	39 57 N	116 28	..	....	....	..	....	27	0.46	−.23	.12	−9
Tokyo	35 41 N	139 45	39	45	+.01	.11	0	36	0.47	+.03	.11	+2
Zikawei	31 12 N	119 6	37	44	−.39	.09	−16	37	0.41	+.15	.11	+6
SOUTH AMERICA NORTH OF 30°S.	S	W										
Bahia	12 54	38 24	20	20	+.12	.15	+4	20	0.53	−.25	.14	−23
Blumenau	26 55	49 3	20	174	+.61	.10	+182	20	0.58	−.50	.11	−51
Para	1 28	48 24	15	20	+.20	.17	+9	..	...	....	..	....
Recife	8 5	34 50	22	105	−.16	.14	−22	22	0.28	−.36	.12	−14
Rio de Janeiro	22 54	43 10	39	68	−.13	.10	−8	39	0.69	−.38	.09	−23
AFRICA NORTH OF 30°S.												
Abbassia	30 5 N	31 17 E	42	62	+.48	.08	+24	40	0.77	−.38	.09	−25
Algiers	36 48 N	3 2 E	24	68	+.42	.11	+41	24	0.54	+.03	.14	+2
Durban	29 51 S	30 30 E	34	71	−.66	.07	−49	33	0.60	+.26	.11	+16
Sierra Leone	8 30 N	13 9 W	..	....	....	..	....	30	0.48	−.30	.09	−13
Zanzibar	6 10 S	39 11 E	22	33	+.33	.13	+18	22	0.26	+.11	.14	+4
TROPICAL OCEANIC ISLANDS												
Honolulu	21 18 N	157 50 W	30	64	+.13	.12	+10	38	0.35	−.67	.06	−21
Malden Island	3 59 S	155 0 W	..	....	....	..	....	27	0.41	−.27	.12	−13
Mauritius	20 6 S	57 33 E	39	58	−.58	.07	−30	38	0.46	−.76	.05	−31
St. Helena	15 55 S	5 43 W	18	34	+.48	.12	+30	27	0.39	+.48	.10	+30
Seychelles	4 45 S	55 45 E	19	38	+.19	.15	+13	20	0.43	−.18	.14	−13
Teneriffe	28 25 N	16 32 W	30	72	−.46	.10	−28	..	...	....	..	....
AUSTRALIA NORTH OF 30°S.	S	E										
Alice Springs	23 38	133 37	31	74	−.06	.12	−4	30	0.71	−.31	.11	−22
Brisbane	27 28	153 6	27	88	+.27	.12	+30	27	0.34	+.59	.08	+26
Carnarvon	24 54	113 39	22	85	+.59	.09	+69	19	0.51	−.70	.08	−46
Derby	17 18	123 39	20	64	+.08	.15	+ 9	19	0.59	−.14	.15	−14
Port Darwin	12 28	130 51	32	81	+.54	.09	+47	36	0.47	−.31	.10	−14
SOUTHERN SOUTH AMERICA	S	W										
Buenos Aires	34 36	58 22	40	60	+.11	.10	+6	43	0.51	−.16	.10	−6
Córdoba	31 25	64 12	41	60	+.25	.10	+13	41	0.61	+.16	.10	+8
Punta Arenas	53 10	70 54	19	150	−.30	.14	−21	20	0.73	−.21	.14	−26
Santiago	33 30	70 30	43	48	+.06	.10	+2	43	0.49	+.07	.10	+3
SOUTH AFRICA	S	E										
Cape Town	33 56	18 29	33	37	−.05	.11	−2	31	0.30	−.37	.10	−12
AUSTRALASIA SOUTH OF 30°S.												
Adelaide	34 57	138 35	33	83	−.17	.11	−15	38	0.36	.00	.11	0
Albany, W. A.	35 2	117 53	24	88	−.31	.12	−41	..	...	....	..	....
Auckland	....	....	..	....	....	..	....	38	0.46	−.37	.09	−13
Perth	31 57	115 52	29	74	−.01	.12	−1	36	0.50	−.59	.07	−26
Sydney	33 52	151 12	43	96	+.47	.08	+37	43	0.25	+.20	.10	+4

THE GOVERNING FACTOR IN TEMPERATURE VARIATION

Two interesting points which arose in the course of the work may be referred to. The first is the distribution of the variation of temperature with time between the mean daily maximum and the mean daily minimum temperatures. Long series were readily available for only three stations, St. Helena, Grenada (West Indies), and Sierra Leone. These showed the following values:

		σ Degrees Centigrade	r	b Degrees Centigrade
St. Helena	Mean maximum . .	0.91	+.69	+.081
	Mean minimum . .	0.31	−.44	−.018
	Mean	0.39	+.48	+.031
Grenada	Mean maximum . . .	0.34	+.39	+.018
	Mean minimum . .	0.21	+.45	+.013
	Mean	0.23	+.45	+.015
Sierra Leone	Mean maximum . .	0.53	−.59	−.023
	Mean minimum . .	0.70	−.05	−.003
	Mean	0.48	−.30	−.013

These three examples show that the governing factor in the temperature variation is the day temperature. In the case of St. Helena we have the remarkable fact that while the maximum temperatures have been increasing, the minima have been decreasing, giving an average increase in the daily range of one degree centigrade in ten years—an important climatological effect. At the other stations the variation of the minima is in the same direction as that of the maxima but is apparently less rapid. A general examination of the figures at seventeen tropical stations was made (see Table III), and, though the series are generally less than twenty years in length, certain facts could be definitely ascertained.

1. Stations may be divided roughly into two groups:
   A. Tropical islands and continental stations in arid districts or at high levels.
   B. Coastal stations.

2. At stations in group A the maxima vary much more than the minima; at coastal stations the ratio ranges about unity.

3. In group A the maxima alone show any marked relation to time, the value of b averaging about 0.14° F., i.e. the mean for the decade 1910–1919 is about 1.4 degrees higher than that for the decade 1900–1909.

It should be noted that the first period (average period about 1903–1909) is one of considerably higher sun-spot numbers than the second (about 1910–1915), which partly accounts for the general rise of temperature shown.

TABLE III—MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURES AT TROPICAL STATIONS
(In degrees Fahrenheit)

	MEAN DAILY MAXIMUM			MEAN DAILY MINIMUM		
	1900–09	1910–19	CHANGE	1900–09	1910–19	CHANGE
A. ISLAND STATIONS						
Fanning Island	85.6	88.2	+2.6	76.7	76.6	−0.1
Malden Island	90.2	90.0	−0.2	75.0	74.3	−0.7
Ocean Island	89.2	88.3	−0.9	75.2	76.2	+1.0
St. Helena	66.3	68.7	+2.4	56.3	56.5	+0.2
Tulagi, Solomon Is. . .	84.7	87.7	+3.0	75.5	76.1	+0.6
Mean	83.2	84.6	+1.4	71.7	71.9	+0.2
INTERIOR STATIONS . .						
Entebbe	78.0	79.1	+1.1	63.2	62.8	−0.4
Kontagora	91.1	93.4	+2.3	68.7	67.9	−0.8
Maiduguri	97.5	97.8	+0.3	67.3	68.3	+1.0
Yola	91.8	93.6	+1.8	70.9	72.2	+1.3
Zungeru	92.2	93.1	+0.9	70.1	70.3	+0.2
Mean	90.1	91.4	+1.3	68.0	68.3	+0.3
B. COASTAL STATIONS						
Accra	85.2	85.4	+0.2	72.4	72.3	−0.1
Bathurst	85.7	86.0	+0.3	69.9	68.9	−1.0
Cape Coast Castle . .	85.5	85.4	−0.1	73.3	71.5	−1.8
Grenada	83.8	84.0	+0.2	73.9	74.2	+0.3
Lagos	86.3	86.9	+0.6	75.0	74.8	−0.2
Sandakan, Borneo . .	88.5	88.7	+0.2	75.5	75.4	−0.1
Sierra Leone	88.2	88.1	−0.1	73.4	72.8	−0.6
Mean	86.2	86.4	+0.2	73.3	72.8	−0.5

NOTE. The series mostly begin about 1903 or 1904 and end about 1917.

TENDENCY TOWARD DECREASING DEVIATION FROM NORMAL

The second point is the remarkable tendency which has existed during the last forty years for a numerical decrease in the deviations from normal. This has been brought out by dividing the whole period at each station into two halves and summing the squares of the deviations independently in each half. Calling the standard deviation of the first period A and that of the second period B, we find the following distribution (only long complete series were used):

		B greater than A B/A			A greater than B A/B		
		>2	2−1.33	1.33−1	1−1.33	1.33−2	>2
Pressure	Number. . . .	0	9	7	9	21	12
	Per cent . . .	0	15	12	16	36	21
Temperature	Number .	2	5	9	19	13	7
	Per cent .	4	9	16	35	23	13

The phenomenon is most marked in the case of pressure, where in 33 cases, or 44 per cent, the standard deviation in the first period exceeded that in the second by at least 33 per cent, while in 12 cases the excess was at least 100 per cent. In temperature the distribution is less striking; but in 71 per cent the deviation in the first period exceeded that in the second and was more than double it in 13 per cent, compared with only 4 per cent when it was less than half. The individual stations were as follows:

Pressure: B/A 2—1.33: Abbassia, Aden, Córdoba, Denver, Galveston, Hamburg, St. Helena, Jacobshavn, Mexico City.

B/A 1.33—1: Basel, Bushire, Leh, Lisbon, Port Darwin, Vienna, Warsaw.

A/B 1—1.33: Batavia, Colombo, Havana, Hongkong, Manila, Skutari, Stykkisholm, Tokyo, Valencia.

A/B 1.33—2: Adelaide, Albany (N. Y.), Archangel, Barnaul, Bombay, Buenos Aires, Calcutta, Cape Town, Christiansund, Honolulu, Mauritius, Perth (W. A.), Petrograd, San Diego, San Juan, (P. R.), Sydney (Nova Scotia), Thorshavn, Tiflis, Toronto, Washington, Zikawei.

A/B more than 2: Agra, Durban, Yeniseisk, Greenwich, Irkutsk, Key West, Lugansk, Rangoon, Rio de Janeiro, Santiago, Sydney (N.S.W.), Vardo.

Temperature: B/A more than 2: Adelaide, Buenos Aires.

B/A 2—1.33: Colombo, Córdoba, Denver, Galveston, Mexico City.

B/A 1.33—1: Bombay, Greenwich, St. Helena, Honolulu, Irkutsk, Jacobshavn, Lugansk, St. Louis, Washington.

A/B 1—1.33: Agra, Archangel, Barnaul, Batavia, Calcutta, Ekaterinburg, Hamburg, Hongkong, Key West, Madras, Manila, Mauritius, Moscow, Petrograd, Port Darwin, San Diego, Sydney (Nova Scotia), Vardo, Zikawei.

A/B 1.33—2: Basel, Cape Town, Christiansund, Kieff, Leh, Nagasaki, Rio de Janeiro, Stykkisholm, Sydney (N.S.W.), Tiflis, Tokyo, Toronto, Vienna.

A/B more than 2: Abbassia, Yeniseisk, Perth (W.A.), Rangoon, Santiago, Thorshavn, Warsaw.

This list shows that both with pressure and temperature the preponderant standard deviation of the earlier years is found chiefly in the belt of decreasing pressure over northern Europe and Siberia and also in India, the West Indies, the New England states, and the eastern coast of Australia. The reverse, B greater than A, is more restricted, being found chiefly in the Mediterranean region and the interior of America. These facts are of great interest; they may be paralleled with the investigations of J. von Hann and Liznar, who found that the absolute variability of temperature as shown by the annual range is greater at times of spot maximum than at spot minimum. A similar result for the range of daily maximum temperatures was found by MacDowall for Geneva. No similar direct results for pressure anomalies have been discovered, but there is a classical paper by Meldrum in which he shows that the cyclones of the Indian Ocean have a marked maximum frequency at spot maximum and minimum frequency at spot minimum. Similar results have been obtained by Poey in the Antilles, and these phenomena may be considered as analogous to the decreasing pressure irregularities with decreasing sun-spot numbers. The two exceptions, the Mediterranean and the interior of the United States, are apparently due to a tendency of depressions to follow more southerly tracks at times of few sun spots, thus increasing the variation of pressure and temperature in the regions traversed by these tracks.

CONCLUSION

Finally, I must admit that the results set out in this paper need to be considered as a preliminary survey only. For the tropical islands especially the series of observations are rarely long enough for such a statistical investigation, though for the purpose of a comparison of solar and terrestrial changes these islands are of great importance as giving relatively simple conditions. But, when it is seen that secular trend may appreciably modify the climate of a place within the relatively short period of forty years, I hope that investigators of the climatic conditions of various localities will realize the importance of this element of climate and, with fuller information at their command, will check the accuracy of the results or fill in the details at present necessarily left blank.